NORTH CAROLINA
DEPARTMENT OF WATER AND AIR RESOURCES

DIVISION OF GROUND WATER

REPORT OF INVESTIGATIONS NO. 6

GROUND-WATER SUPPLY OF CAPE HATTERAS NATIONAL SEASHORE RECREATIONAL AREA, NORTH CAROLINA

PART 5

By
GRANVILLE G. WYRICK AND ROBERTA B. DEAN

RALEIGH, NORTH CAROLINA
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GEORGE E. PICKETT, Director

DIVISION OF GROUND WATER
HARRY M. PEEK, Chief

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U. S. Geological Survey

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
NATIONAL PARK SERVICE

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NORTH CAROLINA

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STATE OF NORTH CAROLINA

DEPARTMENT OF WATER AND AIR RESOURCES

GEORGE E. PICKETT, DIRECTOR
E. C. HUBBARD, ASST. DIRECTOR
P. O. BOX 9392
RALEIGH, N. C. 27603
TELEPHONE 829-3003

June 24, 1968

The Honorable Dan K. Moore
Governor of North Carolina
Raleigh, North Carolina

Dear Governor Moore:

I am pleased to submit Report of Investigations No. 6, "Ground-Water Supply of Cape Hatteras National Seashore Recreational Area, North Carolina, Part 5," prepared by Granville G. Wyrick and Roberta B. Dean, United States Geological Survey, in cooperation with the National Park Service.

This report presents the results of the fifth phase of intensive studies by the Geological Survey to evaluate and aid in the development of ground-water supplies in the National Seashore Recreational Area. The data in this report was collected at the Ocracoke Island lateral well supply.

Respectfully submitted,

George E. Pickett

George E. Pickett

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Part 5

Ocracoke Island Lateral Well Supply

By

Granville G. Wyrick and Roberta B. Dean

INTRODUCTION

The National Park Service requested, in 1965, that the U. S. Geological Survey assist in the design of, and conduct the testing of a lateral well near Try Yard Creek, Ocracoke Island, Cape Hatteras National Seashore Recreational Area, North Carolina. The National Park Service desires a campground site in the general area of Parkers Hill and Try Yard Creek but previous investigations by Kimrey (1960) and Harris and Wilder (1964) indicated that conventional wells could not be used to recover the available fresh water necessary for a campground without inducing salt-water encroachment. Therefore, it was decided to test the use of a shallow lateral well as a source of fresh-water supplies. Planning, construction, and testing of the lateral well was done during 1965.

Work by Geological Survey personnel on this project consisted of consulting with Engineer Vick of the National Park Service on specifications for the lateral well; visiting the well during construction to verify compliance with the specifications; and conducting an extended pumping test on the completed well to determine the safe yield of the well and the treatment required for satisfactory use of the water. Samples for "standard complete" analyses of water were analyzed by the U. S. Geological Survey Water Resources Laboratory in Raleigh, North Carolina.

The authors wish to acknowledge the cooperation of National Park Service personnel under Superintendent Karl T. Gilbert, who assisted in supplying specifications and data during the construction and testing of the well.

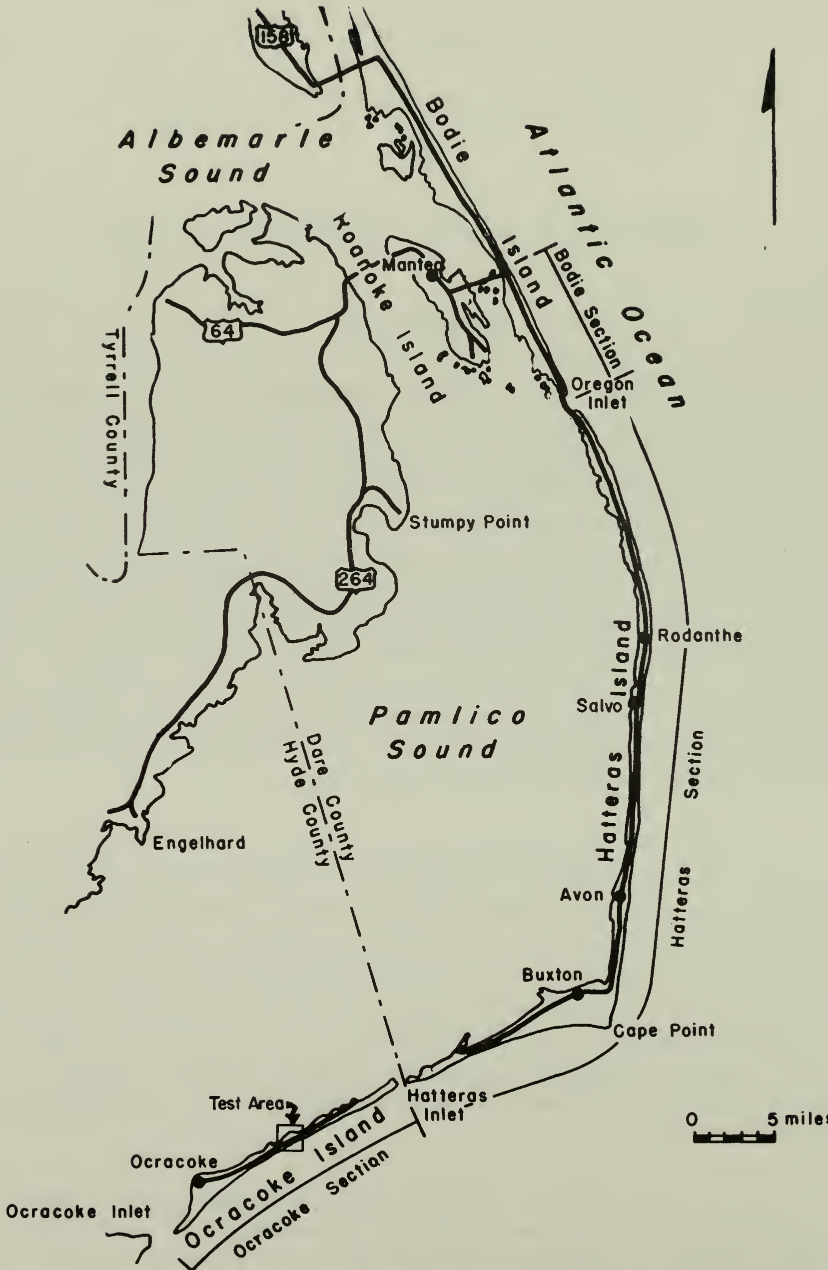

Figure 1-. Cape Hatteras National Seashore Recreational Area showing location of test area

GEOGRAPHY

Ocracoke Island, located on the east coast of North Carolina, is one of three islands comprising Cape Hatteras National Seashore Recreational Area (fig. 1). The islands are a part of what is commonly called the "outer banks" - a group of barrier islands separating the Atlantic Ocean to the east from Albemarle and Pamlico Sounds to the west. Ocracoke Island extends from Hatteras Inlet, on the northeast, for about 13 miles to Ocracoke Inlet on the southwest. The Atlantic Ocean is southeast of the island and Pamlico is northwest of it. The test area is near the center of the island between Try Yard Creek and Knoll House Creek. At the test area the island is about half a mile wide from ocean to sound and the creeks are about half a mile apart (fig. 2).

This area was selected for the test because it contains the most extensive stabilized dune mass on the island. Land surface elevations range from sea level at the ocean and sound to about 30 feet above sea level on the dunes. The dunes are relatively stable in that they are covered with grass and shrubs which prevent their migration by wind erosion.

Precipitation at the test area is estimated at an average of approximately 55 inches per year based upon U. S. Department of Commerce Weather Bureau records from Hatteras Village, about 10 miles northeast. The precipitation records for Ocracoke Village had been reported for 9 years in 1965 and, therefore, no long-term average has been computed. Within the area of pumping influence of the lateral well the average daily precipitation is greater than 14,000 gallons, and within the dune mass the average daily precipitation amounts to more than 88,000 gallons. As there is no surface runoff, all of the precipitation either percolates to the water-table aquifer or is returned to the atmosphere by evaporation and the transpiration of the plants.

PREVIOUS INVESTIGATIONS

Previous investigations of sources of ground-water supply at Ocracoke Island and at other sites in the Park, were of particular significance to this study for two reasons. First, studies at Ocracoke Island indicated that the test site was the most promising area for producing a fresh-water supply but that

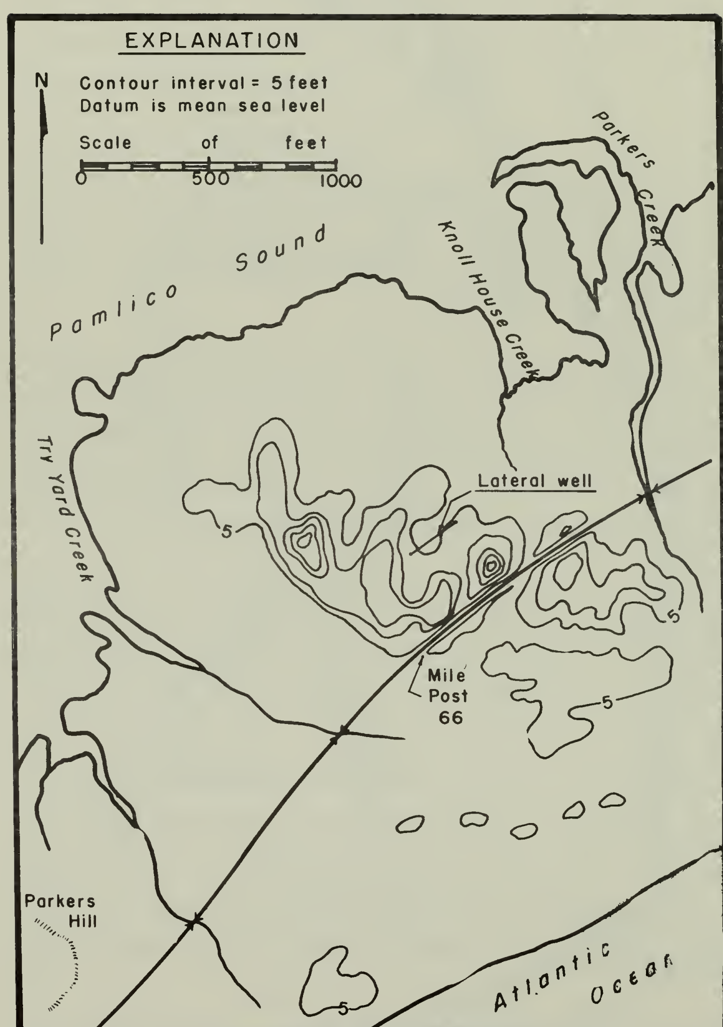

Figure 2-. Parkers Hill well site

such a supply could not be produced by conventional wells. Second, a similar, lateral well was constructed and tested at Salvo, Hatteras Island, from which data were obtained for developing design specifications and test techniques for the Ocracoke lateral well.

The area is generally described by Kimrey (1960) and Harris and Wilder (1964) as having a fine-to medium-grained sand unit from land surface to depths of 70 to 90 feet. This sand unit is the water-table aquifer, containing fresh water in the upper 25 to 50 feet. The fresh water is underlain by salt water which contains chlorides in excess of 12,000 ppm (parts per million) at depths of about 90 feet. Both studies included pumping tests of the 20 - 30 foot depth and both indicated that salt-water encroachment would occur after pumping 20 to 30 gpm (gallons per minute) for extended periods. Kimrey's report suggested the use of a lateral well for recovering fresh water 1.2 miles southwest of the Parkers Hill site. However, the site near Parkers Hill includes a larger dune mass than the site suggested by Kimrey and it was therefore decided to construct a lateral well near Parkers Hill similar to the one at Salvo Campground.

The Salvo lateral well was constructed by laying a 2-inch diameter pipe line of 20-foot lengths of pipe alternating with 5-foot screens in a gravel-packed ditch. The ditch was about 125 feet long and about one-foot square in the gravel-packed section. The screened line was set laterally, near the center of the gravel pack, and slightly below mean sea level. It was determined by tests that salt water occurred about 10 feet below the well and encroached vertically upward to the well when pumping rates were greater than 9 gpm. Based upon the Salvo-well data and the need for a larger yield, the specifications for the Ocracoke well were designed for a pumping rate of 15-20 gpm. An intermittent large yield was desirable so that the water system could supply sufficient water during peak-load periods without the necessity of constructing extensive water storage facilities.

WELL CONSTRUCTION

Location

The site for well construction in the dunes was selected for several reasons (fig. 2). First, by constructing the well

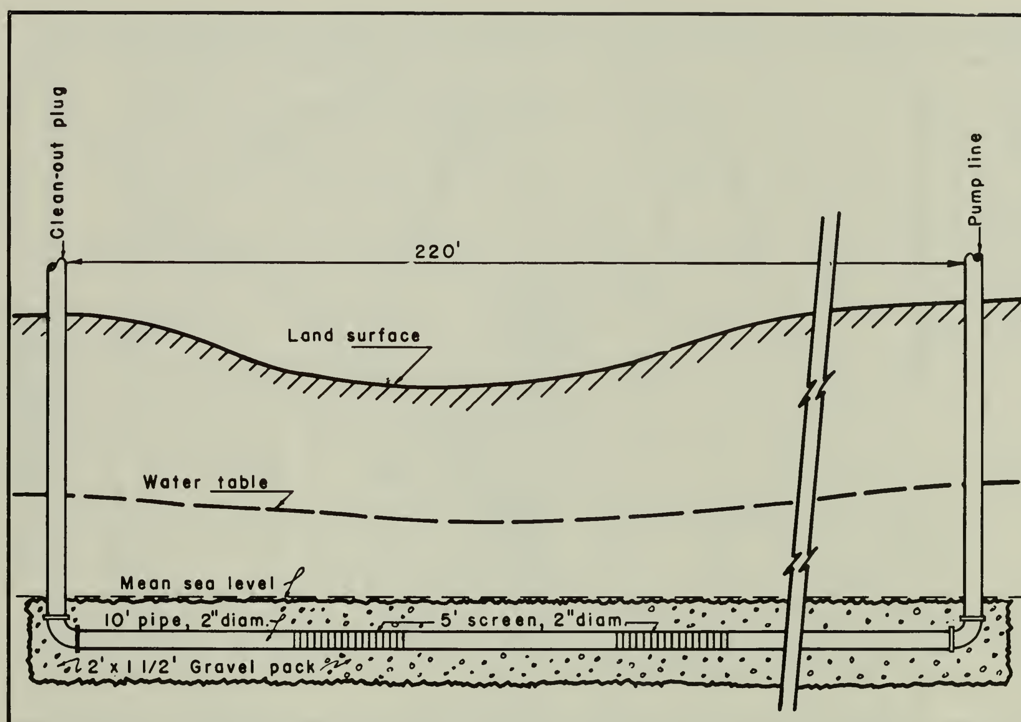

Figure 3_. Generalized diagram of lateral well design

across a draw in the U-shaped dune, the well would be protected from salt-water flooding on three sides by the dune mass. Second, the well intercepts ground water that normally flows from the dunes toward the sound. And, third, the depth to salt water was greater than 30 feet below land surface at this site.

Well Specification

The generalized well specifications required that a line of plastic pipe and screens be set horizontally, about one foot below mean sea level, in a gravel-packed ditch (fig. 3). The pipe and screened line was to be approximately 220 feet long, 2 inches in diameter, with alternating sections of 10-foot lengths of plastic pipe and 5-foot lengths of plastic screen. The line was to be set in the center of a gravel-packed ditch. The gravel pack was to be 2 feet deep by 1½ feet wide, and its top was to be approximately at mean sea level. The ditch above the gravel pack was to be back-filled with sand to or above normal land surface. The gravel size in the pack was uniformly graded from coarse-sand size to pea-gravel size. The well was to be finished with a vertical pipe extending from each end of the line to about 2 feet above land surface. The well was constructed according to these specifications during the fall of 1965.

WELL TEST

The U. S. Geological Survey installed seven observation wells near the lateral well (fig. 4) upon completion of its construction. These seven wells, with three from previous studies, were for observing changes in water levels and chemical quality of water from the aquifer during an extended pumping test. All the wells were screened at depths of about 10 feet below land surface except the one near the center of the lateral well which was screened about 20 feet below land surface (fig. 4). The well in the 20-foot zone was used to collect water samples from a depth approximately 10 feet below the lateral well.

A staff gage was installed at the bridge over Parkers Creek to measure changes in water levels due to tidal fluctuations.

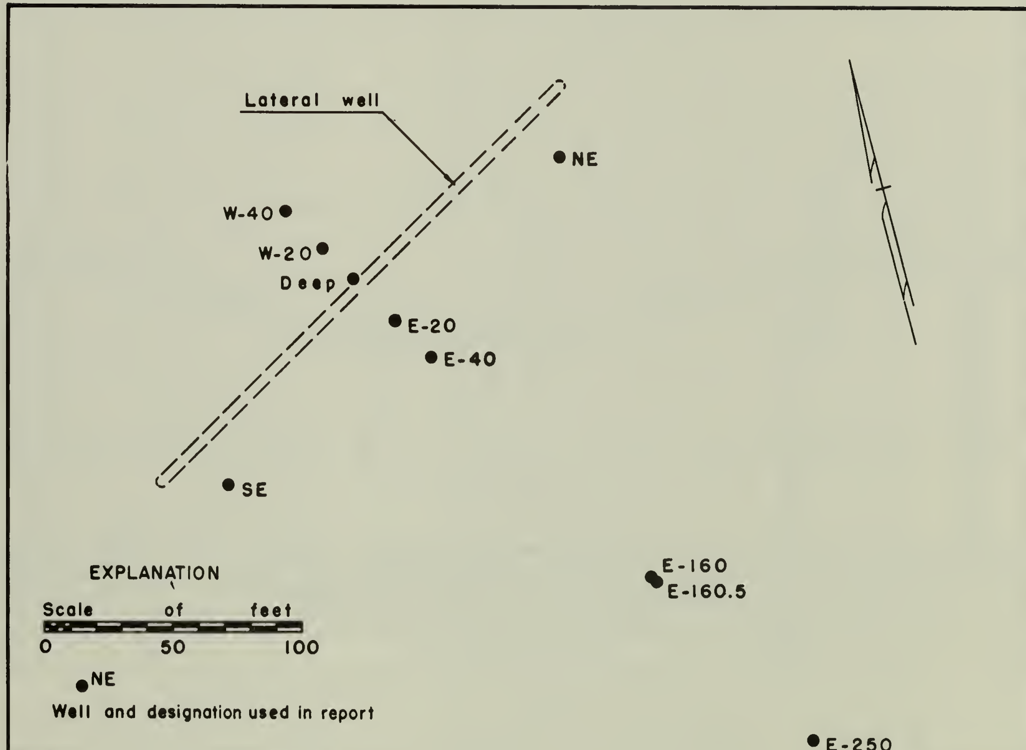

Figure 4-. Well locations

The pumping test was planned for 5-days duration. The pumping rate was scheduled at 15 gpm for the first 24 hours, 20 gpm for the next 48 hours, and 25 gpm for the last 24 hours of pumping, with recovery measurements for 24 hours after pumping stopped. When pumping was increased to 25 gpm, the water table was lowered to the well screens allowing air to enter the system, and the pump broke suction. Thereafter the pumping rate was held at 22 gpm for the final 24 hours of the test. After the first hour of pumping, water level measurements were made in the shallow observation wells at 1-hour intervals during the remainder of the test. Water samples for partial chemical analyses were collected from the discharge of the pump and from the deep well, and staff gage readings were made at 1-hour intervals during the test. These data were used to determine the safe yield of the lateral well.

In the other well fields at Cape Hatteras National Seashore Recreational Area, the safe yield of the wells depends primarily upon changes in water quality as related to pumping rate. However, at the Ocracoke site the test indicates that the safe yield is dependent more upon the hydrology of the aquifer than adverse changes in water quality during short periods of pumping. That is, the well cannot be pumped at a rate high enough to induce salt-water encroachment without lowering the water table to the well screens, and thus break pump suction. Therefore, the "safe yield" of this well for periods of pumpage less than one month is the rate at which the well will produce water without lowering the water table to the well screens.

Several methods were used to establish a pumping rate which would not result in excessive lowering of the water table. First, the specific yield (gallons per foot of drawdown) of the well was determined by pumping. Then the seasonal low levels of the water table were established to determine the maximum allowable drawdown. And finally, the effects of tides, precipitation, and velocity of ground-water flow were considered for predicting changes in the natural levels of the water table.

The pumping test began at 8:35 A.M., November 15, 1965. The pumping rate was set at 15 gpm and measurements of water-level changes were made at 5- and 10-minute intervals for the first hour. After the first hour, measurements were made at 1-hour intervals. The hydrographs in figures 5 through 10 show the changes during the test. The specific yield of the well

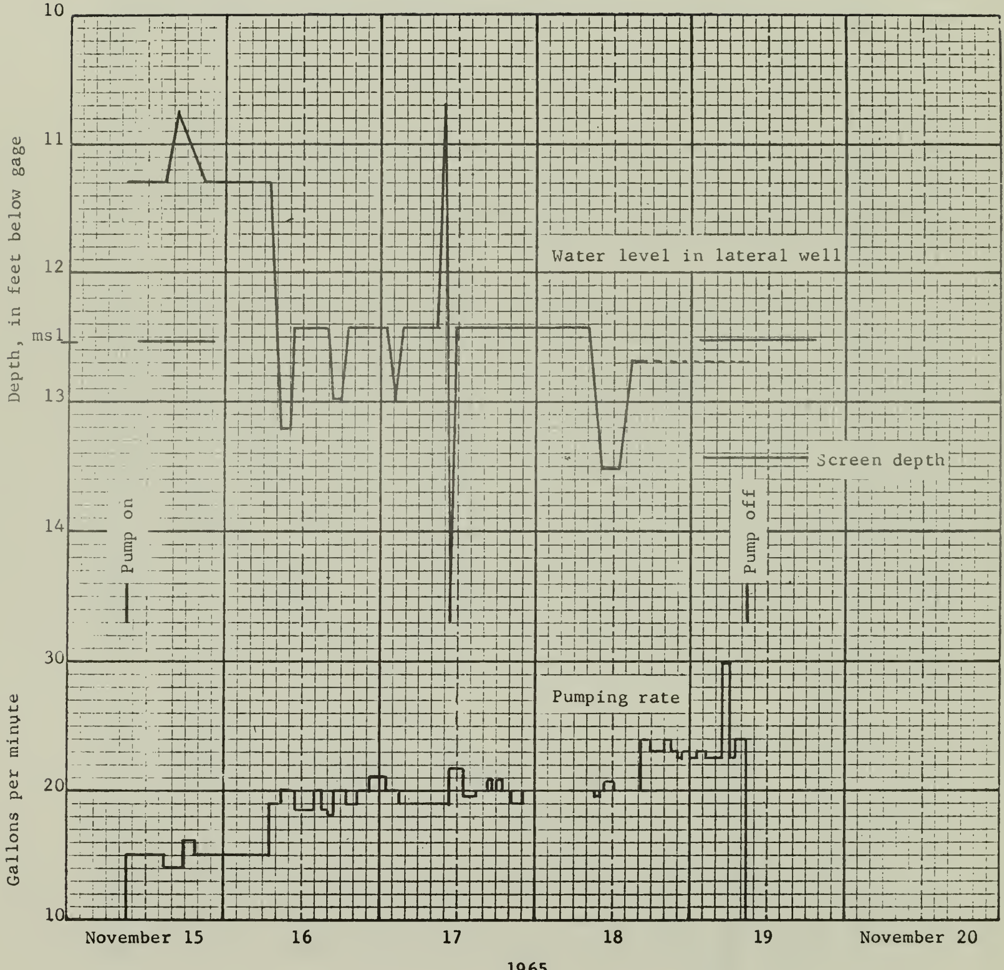

Figure 5-. Graphs showing water levels in lateral well as compared to pumping rates during the test at Parkers Hill site November 15-20, 1965

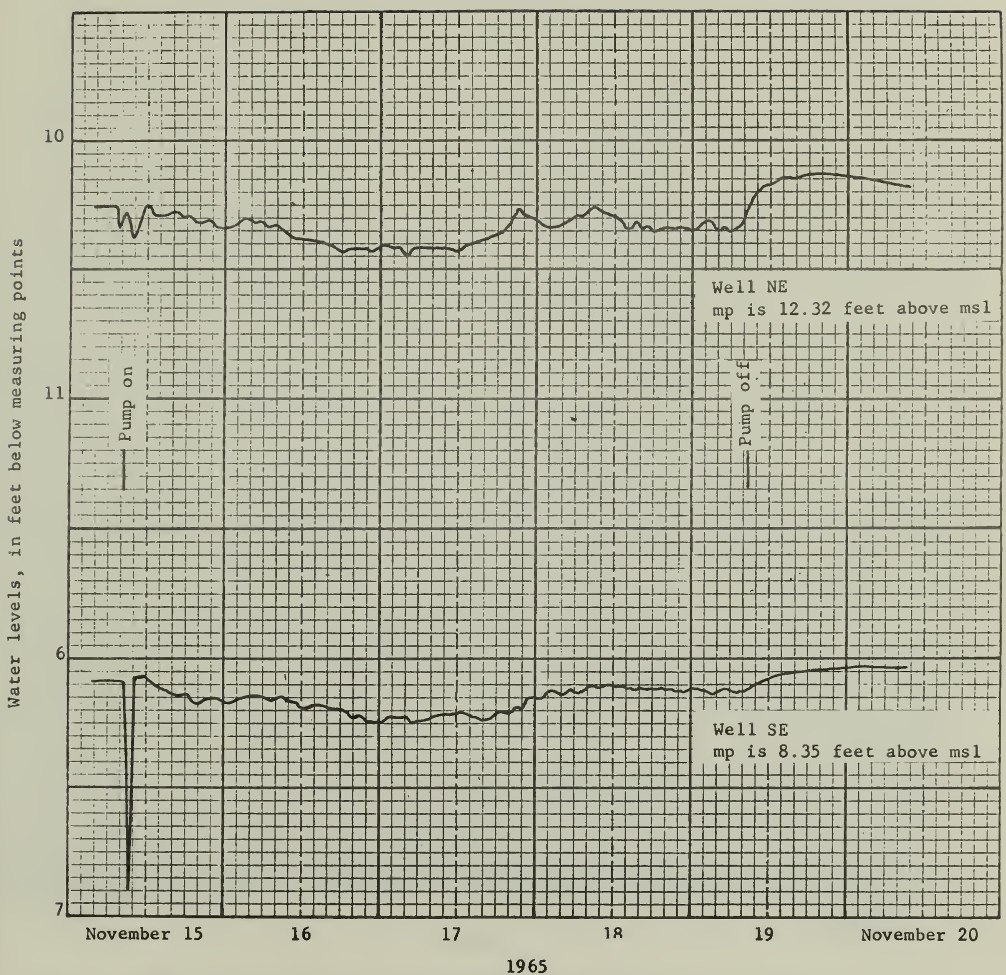

Figure 6-. Hydrographs showing fluctuations of water levels in observation wells "NE" and "SE" at Parkers Hill site

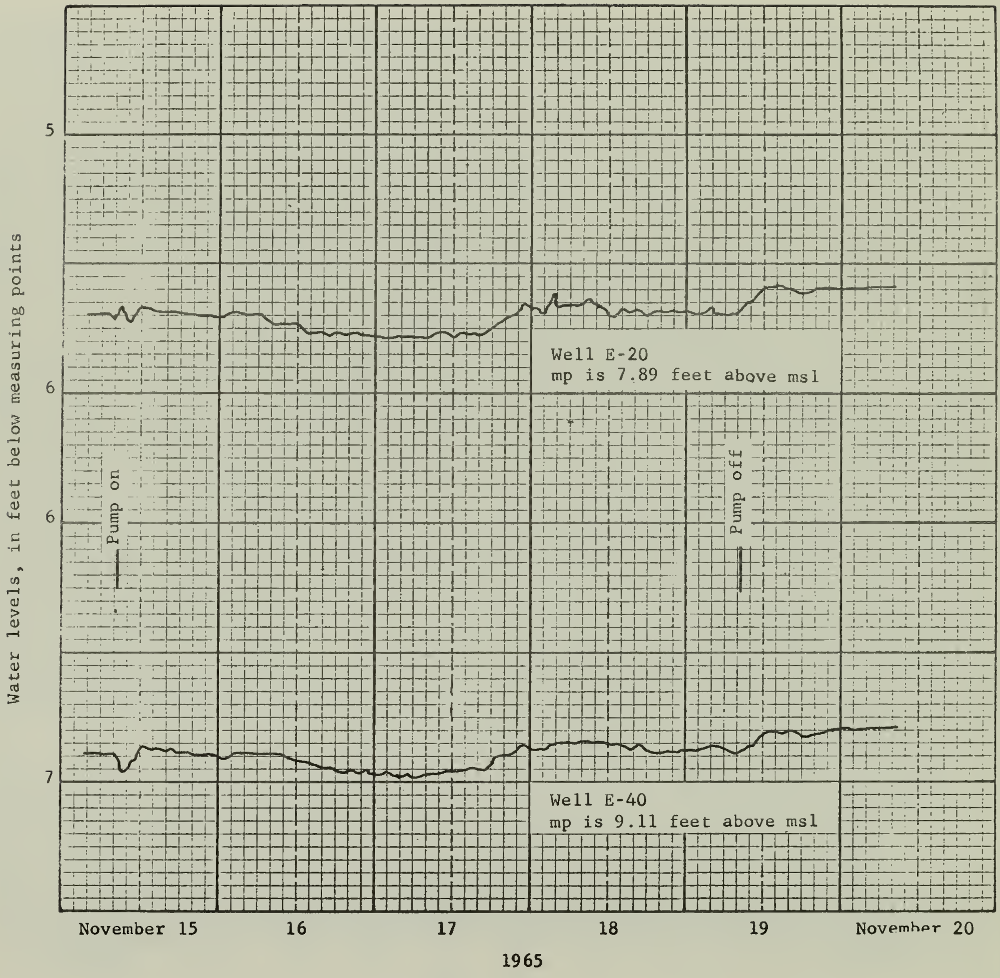

Figure 7-. Hydrographs showing fluctuations of water levels in observation wells "E-20" and "E-40" at Parkers Hill site

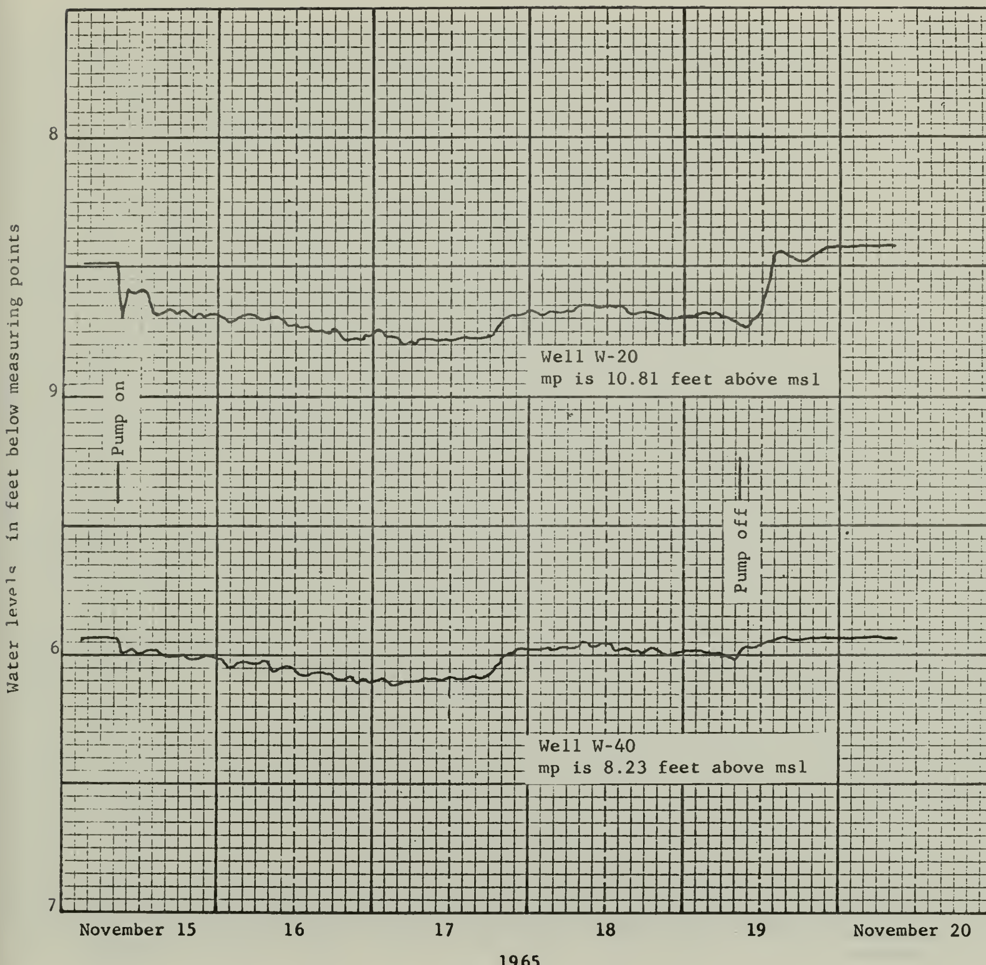

Figure 8- Hydrographs showing fluctuations of water levels in observation wells "West-20" and "West-40" at Parkers Hill site

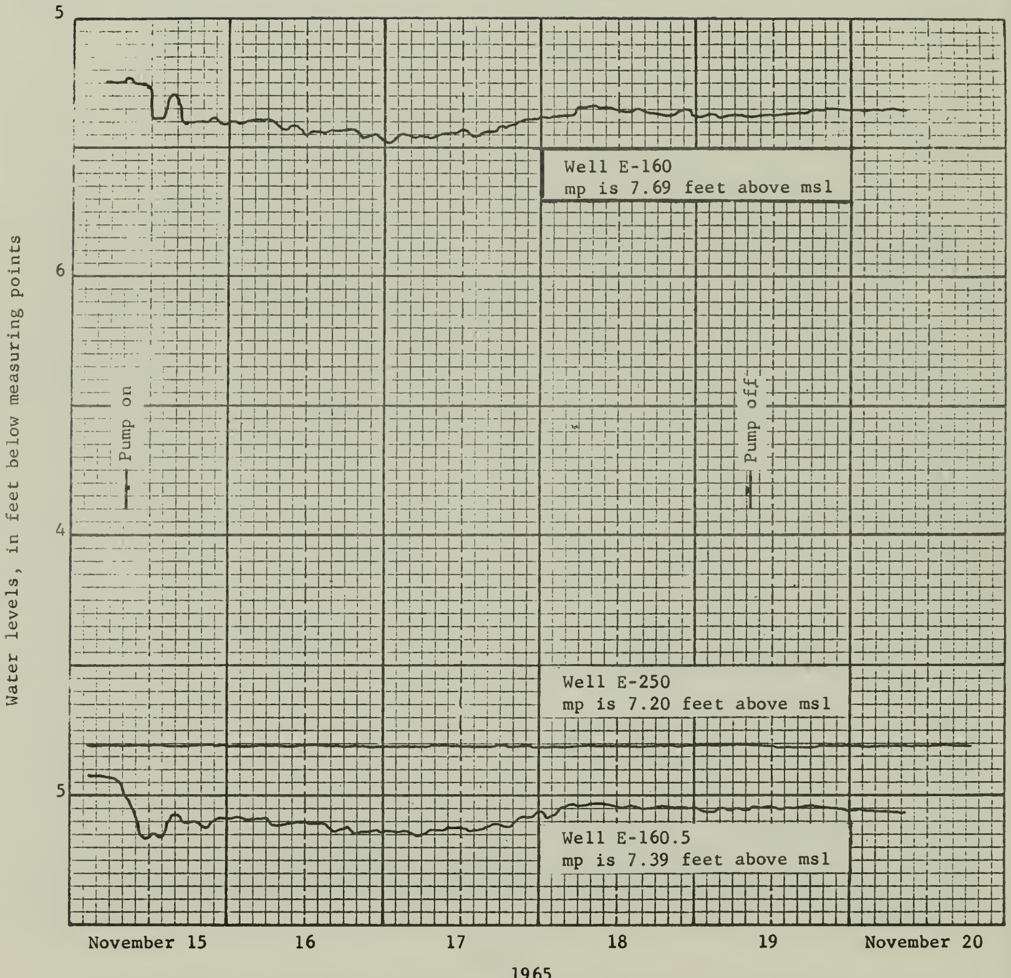

Figure 9-. Hydrographs showing fluctuations of water levels in observation wells "160, 162, and 250" at Parkers Hill site

Figure 10-. Hydrograpn showing fluctuation of water levels in Parkers Creek

after 24 hours of pumping at 15 gpm was determined to be 7.9 gallons per minute per foot of drawdown (gpm/ft.). After 72 hours of pumping, the last 48 hours at 20 gpm, the specific yield was calculated at 7.0 gpm/ft. Using a specific yield of 7.0 gpm/ft., pumping at a rate of 20 gpm would result in a drawdown of 2.8 feet after 72 hours of continuous pumpage. As it is not anticipated that the well will be pumped continuously for more than 24 hours, the drawdown value was considered reasonable for calculations of predicted pumping effects.

The mean water level at the Parkers Hill site for 1965 was about 2.5 feet above msl (fig. 11). As the rainfall for 1965 was about 9 inches less than normal, the mean-annual level for the water table can reasonably be expected to exceed 2.5 feet above msl. Considering the mean annual water level to be 2.5 feet above msl, plus the additional 1 foot of water below msl to the top of the screens, a drawdown of 2.8 feet would leave the water level nearly 1 foot above the screens. This is based upon mean water levels, but pumping may occur during periods of lower-than-mean water levels, so calculations were made for the lowest levels measured during a 3-year period of record. The lowest water level on record was at 1.86 feet above msl on June 8, 1965. This level, plus the 1 foot below msl to the screens, would also allow 2.8 feet of drawdown at the well.

The level of the water table fluctuates with tidal effects in addition to the fluctuations due to precipitation. Therefore, it was considered necessary to calculate the amount of changes in water level at the well due to tidal changes in the sound. Using records from the observation wells and the staff gage, it was determined that changes in water level at the center of the lateral well were 11 percent of changes in sound level due to tides. Thus, a decline of 1 foot below msl in sound level would result in a decline of 0.11 feet in water level at the well. The tidal range is seldom more than 2 feet and the tidal efficiency of the aquifer is low; therefore, limitations in pumping rate to allow for tidal effects are not considered necessary.

Once a maximum pumping rate was established for the well, velocities of ground-water flow under natural conditions and pumping conditions were considered to determine the probability of salt-water encroachment to the well. Based upon average water-level differences between the ground-water levels in the

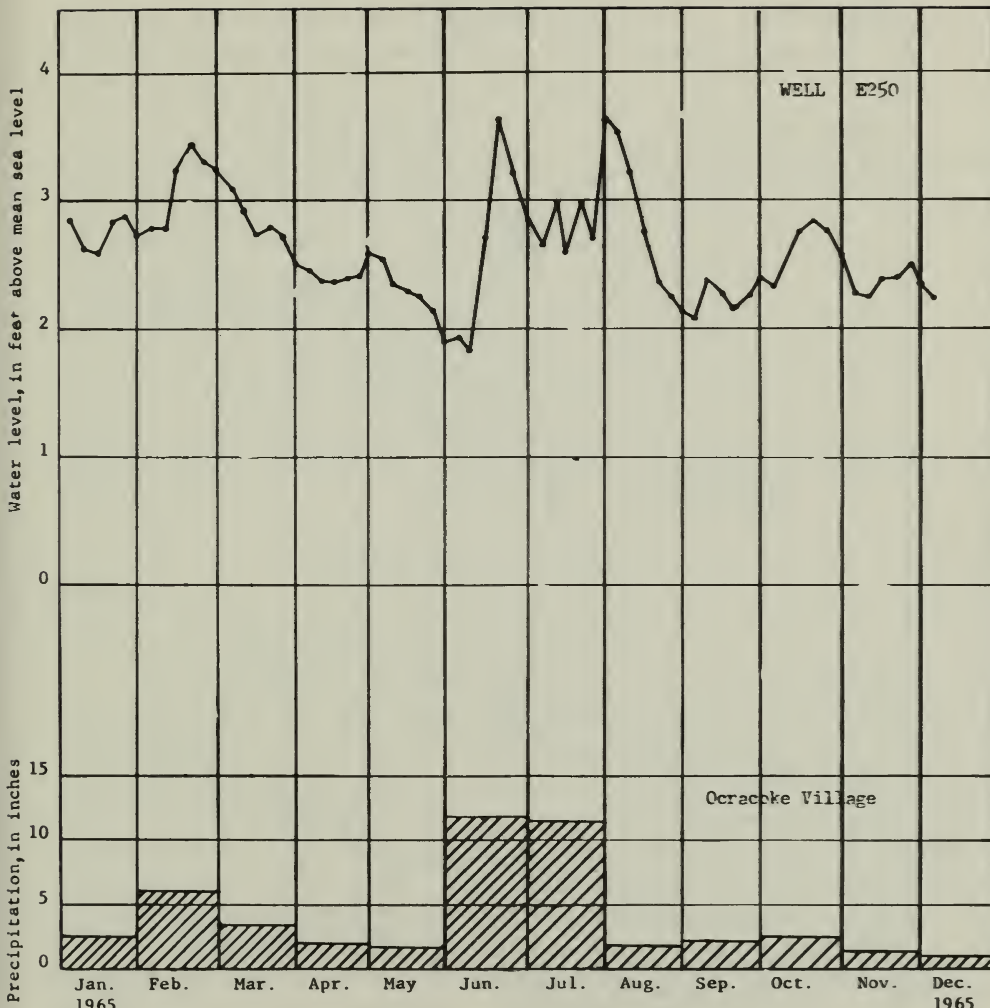

Figure 11-. Graphs of precipitation and ground-water levels near Parkers Hill, 1965

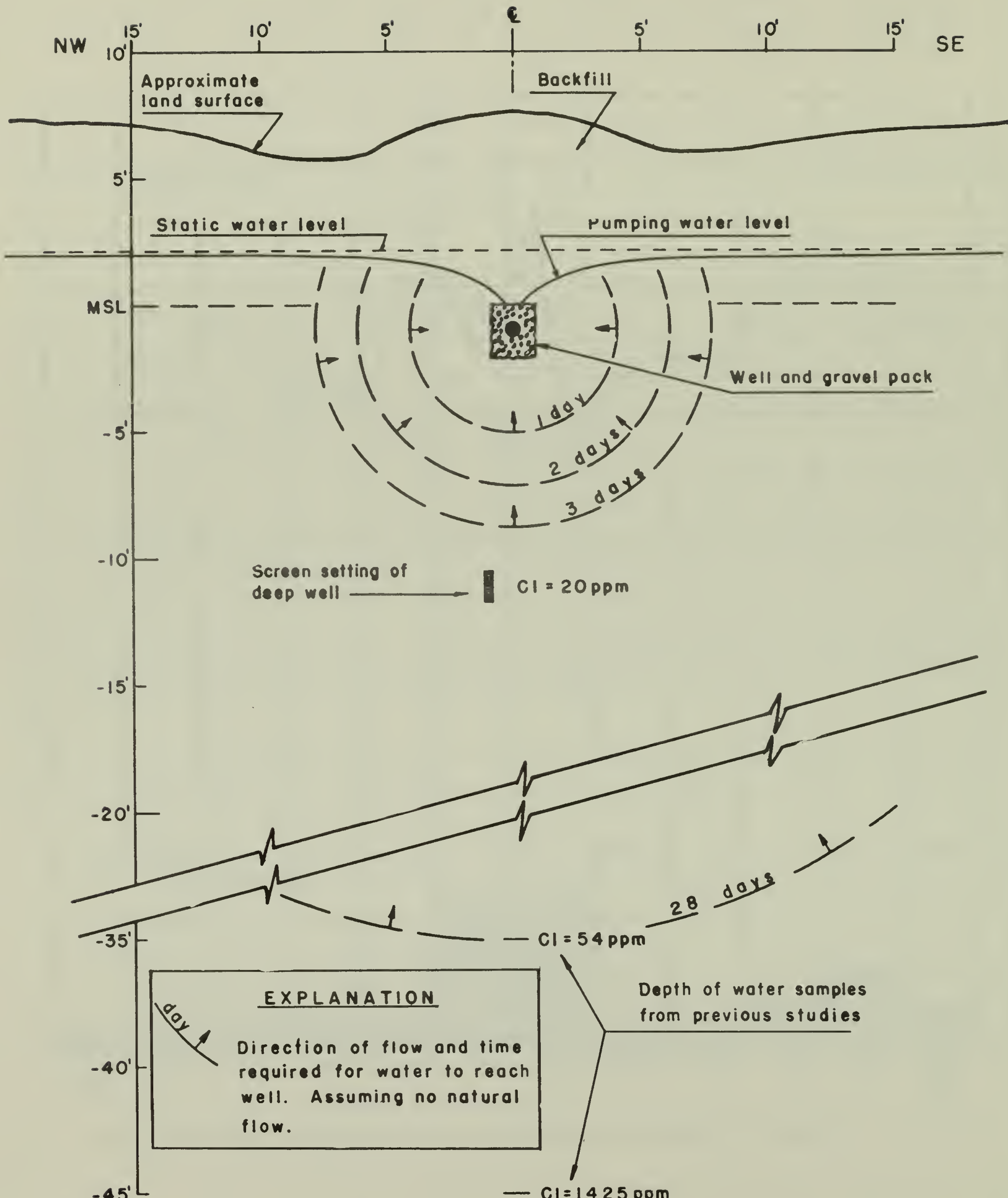

Figure 12-. Generalized hydrologic section through the center of the lateral well

dunes and near the sound, the linear distance from the dunes to the sound, and porosity of the sand, the average velocity of ground-water flow was calculated to be about 0.6 feet per day. Thus, the natural flow of water would move horizontally under and past the unpumped well at about 0.6 feet per day. The velocity of flow toward the pumping well, disregarding natural flow during the test is shown in figure 12. At the end of the first day of pumping at 15 gpm, water had moved from 4.1 feet away from the well to the well. By the end of the second day, with the discharge increased to 20 gpm, water had moved from 6.2 feet to the well. Thus, it would require more than 30 days of continuous pumping at 20 gpm for salt water to move from a depth of about 40 feet to the well. During the 30-day period for upward encroachment, natural flow would flush the salt water about 18 feet toward the sound. With intermittent pumping (8- or 12-hour cycles) the indications are that salt water would not reach the well in sufficient concentrations to constitute a problem. The velocity analysis in figure 12 is also used to explain changes in other chemical constituents in water during the test.

CHEMICAL QUALITY OF WATER

Occurrence of Fresh Water

Fresh ground water at the Ocracoke test site is derived from precipitation that falls on the land surface and percolates downward to the water table. The precipitation generally contains low concentrations of dissolved minerals when it seeps into the porous sand at land surface. Water percolating from land surface to the water table may contain dissolved carbon dioxide and organic acids. These constituents cause the water to be acidic and an effective solvent for iron and manganese-bearing minerals in the sediments. Thus, when recharge water reaches the water table, it generally is acidic and contains dissolved iron and manganese. As water moves from the water table downward into the aquifer and toward a place of discharge, it flows through sediments containing shell fragments and other material which may cause changes in the water quality. The acidic water may dissolve calcium and magnesium carbonates from shell fragments, causing the water to become more alkaline and to have a higher concentration of hardness. As the water becomes more alkaline, iron and manganese are precipitated in the aquifer and their concentration in the water

decreases. The degree of quality of water change is dependent to some extent upon the rate at which recharge occurs. During short periods of heavy precipitation and rapid recharge, the mineralization of the water is less than during long periods of light precipitation and slow recharge. Thus, water that recharged the aquifer in June and July 1965 (fig. 11) is less mineralized than water that recharged the aquifer from July until the test. Also, based upon figure 11, the less mineralized water from recharge in June and July would have been deeper than 5 feet below the water table at the start of the test and the more mineralized water from subsequent recharge would have been the upper 5 feet of water in the aquifer. Therefore, since the well was in the upper part of the aquifer, the water pumped during the initial part of the test should have been more highly mineralized than water pumped during the latter part of the test. The following discussion of data collected during the test indicates that this occurred.

Changes in Quality of Water During the Test

Water samples were collected and analyzed periodically for specific conductance (micromhos), chloride (Cl, ppm), hydrogen sulfide (H_2S, ppm), and acidity measured as pH from both the lateral well and deep well during the test. These analyses were made to detect changes in chemical quality during pumping and thus aid in determining safe yield (fig. 13, 14). The water samples were collected from the lateral well at the beginning and at the end of the test for "standard complete" laboratory analyses (table 1). The water from the lateral well had a higher specific conductance, lower pH, and the concentrations of chloride and hydrogen sulfide were slightly higher than the water from the deep well. (See figures 13 and 14). The water from the lateral well improved in quality with pumping, whereas the quality of water from the deep well remained fairly constant. The greatest change in quality of the water from the lateral well occurred within the first 2 days of pumping.

The most significant changes in quality from the beginning to the end of the test were in the concentrations of calcium, bicarbonate, iron, and manganese. These quality changes were due to mixing of the water in the lateral well with the less mineralized water from the vicinity of the deep well, approximately 10 feet below the lateral well. A velocity analysis indicated that water in the lateral well at the end of 2 days had moved from a distance of 6.2 feet in the aquifer (fig. 12).

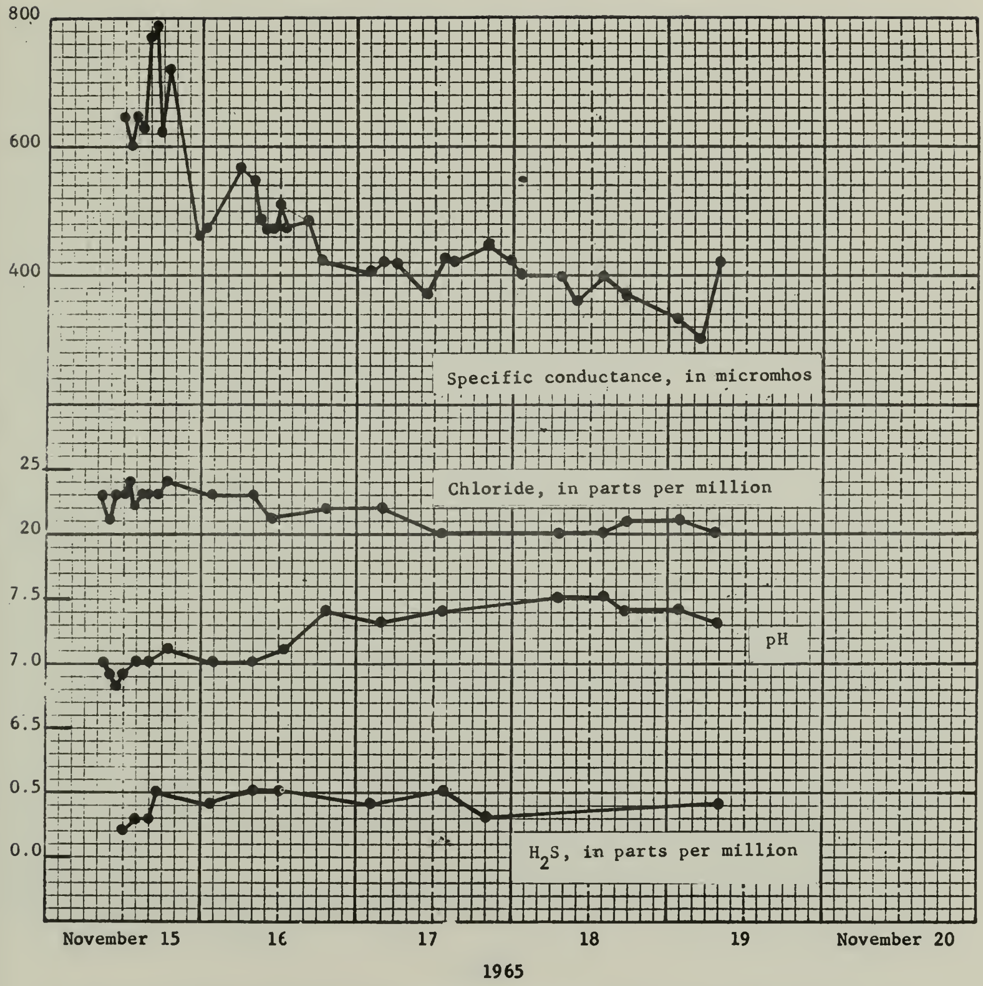

Figure 13-. Graphs showing fluctuations of chemical quality in water from lateral well during the test at Parkers Hill site November, 1965

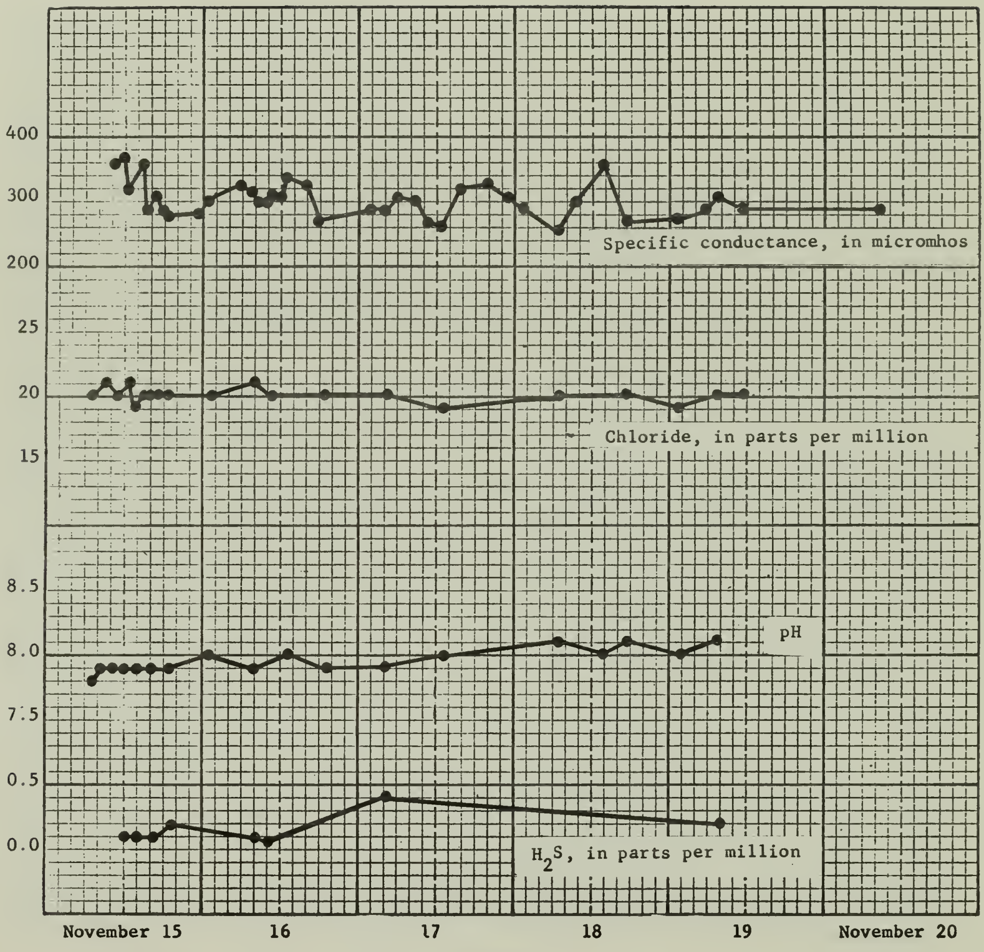

Figure 14-. Graphs showing fluctuations of chemical quality in water from deep observation well during the test at Parkers Hill site November, 1965

TABLE I. ANALYSES OF WATER FROM THE LATERAL WELL NEAR PARKERS HILL, OCRACOKE ISLAND

Date of collection	November 15, 1965	November 19, 1965
Hours of pumping	6	76
Silica (SiO_2)	7.5	6.3
Iron (Fe) (total)	5.8	1.5
Manganese (Mn)	.80	.17
Calcium (Ca)	98	60
Magnesium (Mg)	12	5.6
Sodium (Na)	14	13
Potassium (K)	3.5	1.0
Bicarbonate (HCO_3)	355	199
Carbonate (CO_3)	0	0
Carbon dioxide (CO_2) (Calculated)	28	6.0
Sulfate (SO_4)	5.2	7.2
Chloride (Cl)	22	21
Fluoride (F)	.2	.0
Nitrate (NO_3)	.7	.2
Phosphate (PO_4)	.0	.0
Sum (ppm)	340	213
Hardness (as $CaCO_3$)	298	173
Noncarbonate Hardness	8	10
Specific Conductance (micromhos at 25°C)	597	382
pH	7.3	7.7
Color	50	30

Significant Chemical Constituents

Chloride

Since chloride is the principal anion in ocean water, the measurement of the chloride content of ground water in areas adjacent to the ocean is used to detect salt-water encroachment. The chloride content of ground water in such areas is influenced by rainfall, tides, and the vertical and lateral movement of water underground.

The chloride content of water from both the lateral and the deep observation well was not significantly affected by continued pumping or increases in the pumping rate. Results of a pumping test on a conventional well by Harris and Wilder (1964) indicated upward leakage of salt water after 10 hours of pumping.

The chloride content of the water from the lateral well ranged from 20 - 24 ppm with a slight decreasing trend near the end of the test. The chloride content of the water from the deeper observation well fluctuated from 19 - 21 ppm throughout the test. Water containing less than 250 ppm chloride is considered suitable for public supplies by U. S. Public Health Standards (1962). There is no economical, satisfactory treatment available for lowering the chloride content of water used for domestic purposes.

Specific conductance

Generally, as the concentration of dissolved minerals increases, the specific conductance of the water increases. Thus, measurements of the specific conductance in field investigations are used to indicate changes in the amount of dissolved minerals in the water.

The specific conductance of the water from the lateral well decreased from 597 (micromhos) to 382 during the test due to the decrease in calcium and bicarbonate ions. There was no significant decreasing or increasing trend in the specific conductance of the water from the deep well, indicating only slight fluctuations in water quality.

Hardness of water is due to the presence of alkaline-earth minerals in solution, principally calcium and magnesium. Hardness is an indication of the soap-consuming ability of a water and can be recognized by the curd that is formed with soap. All hardness causing constituents dissolved in water are reported together in terms of an equivalent amount of calcium carbonate ($CaCO_3$).

One of the most significant changes in quality of the water from the lateral well during the pumping test was the decrease in hardness from 298 ppm to 173 ppm. Since the hardness was mainly due to the presence of calcium, its decrease was responsible for the change.

Hard water is generally classified by the U. S. Geological Survey as containing between 120 and 180 ppm ($CaCO_3$). Treatment for lowering hardness is not generally considered necessary for water-supply installations where the water is to be used primarily for drinking purposes.

Iron

The presence of iron in ground water is generally associated with an acidic and reducing environment which promotes the solution of iron-bearing minerals in contact with ground water. The presence of decomposing organic matter produces such an environment. Water containing large amounts of iron has an objectionable taste and tends to stain laundry and porcelain fixtures. Such water may be treated economically by aeration and filtration (Nordell 1961). The U. S. Public Health Service (1962) recommends that the concentration of iron in domestic supplies not exceed 0.3 ppm. This limit is based on esthetic and taste considerations rather than toxicity.

The water from the lateral well had an iron concentration of 5.8 ppm at the beginning of the test, but it had decreased to 1.5 ppm by the end of the test. Since these concentrations may be objectionable, treatment for the removal of iron by aeration and filtration is recommended in the development of a water supply in this area.

Manganese

A reducing environment aided by the presence of dissolved carbon dioxide and certain types of bacteria promote the solution of manganese-bearing minerals in contact with ground water. Manganese resembles iron in its chemical behavior and in its occurrence in ground water, however the concentration is generally less than that of iron. Waters containing manganese in concentrations greater than 0.5 ppm are objectionable for use in public supplies because of the tendency for brownish deposits to form on laundry and plumbing fixtures (Rainwater and Thatcher, 1960). Also, the taste of beverages such as coffee or tea are impaired by use of water containing high concentrations of manganese.

U. S. Public Health (1962) recommends that manganese should be limited to a maximum concentration of .05 ppm in water used for a public supply, but there is no mandatory maximum limit of manganese for the rejection of a supply. Manganese content may be lowered by aeration and filtration in a manner similar to that used for iron (Nordell, 1961). The manganese content of the water from the lateral well decreased from .80 to .17 ppm during the test. Since this concentration may be somewhat objectionable for esthetic reasons, treatment for lowering the manganese content by aeration and filtration should be considered in the development of this water supply.

Organic color

The presence of organic matter in shallow aquifers may impart a characteristic brown color to the water. Organic color in excess of 15 units (U.S.P.H., 1962) is objectionable for esthetic reasons and may result in laundry stains. Removal of organic color is difficult and is not economically feasible in small water-supply installations. Organic color was present in the water from the lateral well, but not in amounts that would justify treatment for its removal.

Hydrogen sulfide

Hydrogen sulfide is a gas produced by the anaerobic decomposition of organic matter or the solution of sulfide minerals. Water having a hydrogen sulfide content in excess of 0.5 ppm has a strong, disagreeable odor characteristic of rotten eggs. Hydrogen sulfide may be removed economically by aeration and/or chlorination (Nordell, 1961).

The hydrogen sulfide content of the water from the lateral well ranged from 0.2 ppm to 0.5 ppm during the test with an average of 0.4 ppm. The hydrogen sulfide content of the water from the deep well ranged from 0.1 ppm to 0.4 ppm with an average of 0.3 ppm. Treatment by aeration and chlorination for the removal of hydrogen sulfide is recommended for this water supply.

Acidity and alkalinity

The pH values are used as a measure of the acidity or alkalinity of the water. The solubility of iron and calcium minerals in particular are affected by changes in the pH of water. Changes in pH are also indications of changes in the balance of chemical equilibria existing in the water. The pH value of 7 is regarded as neutral, values below 7 indicate acidic properties, and values above 7 indicate alkalinity.

The pH of the water from both the lateral well and deep well was slightly alkaline and increased in alkalinity during the test. The pH of the water from the lateral well ranged from 6.8 - 7.5 and the pH of the water from the deep well ranged from 7.9 - 8.1 during the test.

CONCLUSIONS

The test of the lateral well at Ocracoke indicates that this method of well construction is a practical solution for recovering fresh ground water in beach areas closely underlain by salt water. Two factors limit the amount of water that can be obtained from the Ocracoke well. Because of the limitations, the water should be used only for drinking water at the campground and sanitary facilities should be supplied from deeper wells. The limiting factors are:

1. The pumping rate should not exceed 20 gpm in order to prevent drawing the water levels down to the well screens.

2. Pumping at 20 gpm should be intermittent to allow sufficient time for natural ground-water flow to flush the upward movement of salt water away from the well. A pumping period of 8 hours in each 24 hours should furnish about 10,000 gpd for the campground without inducing salt water encroachment to the well.

The water should be treated for iron, manganese, and hydrogen sulfide, which were the only chemical constituents present in concentrations that would contribute undesirable characteristics to the water. These constituents are not considered harmful physiologically, but are undesirable for esthetic reasons. Treatment recommended for the development of a water supply for drinking purposes should include aeration, filtration, and chlorination.

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